



INTEGRATED MANAGEMENT AND MAINTENANCE SYSTEM IMPROVING THE ENERGY EFFICIENCY IN BIOMASS MANUFACTURING

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INTRODUCTION

- Renewable energy sources will play an important role
 - in the sustainable development in the future,
 - protection of the environment and
 - the security of energy supply being the main driving forces in the short term.
 - Utilization of renewable resources is important factor for reduction of emissions of green house gasses, and reduction of use of fossil fuels whose resources are limited.
 - Increased usage of bio energy will also help to control the climate changes and carbon dioxide emissions and social acceptance due to climate change control is reached.
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INTRODUCTION

- Compared to other energy sources, biomass offers many advantages.
- It is possible to use it as liquid, solid or gaseous energy carrier.
- Thus, biomass can be used to create all forms of necessary energy (*electricity, heat and fuel*) in contrast to other renewable resources.
- Another advantage is that biomass can be easily stored and then made available flexibly.
- Recent years have therefore seen considerable effort devoted to the search for the best ways to use these potentially valuable sources of energy.

INTRODUCTION

- Industrial companies must improve their efficiency and reduce costs in order to remain competitive and economically viable.
- Effective maintenance support systems are main area of focus nowadays.
- Different strategies have been adapted to assess machinery condition in real time and to avoid costly maintenance procedures.
- Condition Based Maintenance (CBM) strategy facilitates the competitive needs of industry by preventing costly maintenance activities, and thus, improving availability, reliability and security of machinery.

INTRODUCTION

- In CBM, researchers show keen interest in less developed phase of prognostics that determines or predicts the remaining useful life (RUL) of a system (machinery) under certain operational conditions.
- However, accurate prognostic systems are still scarce in the industry and need for an improvement is inevitable.
- Mainly, the degradation process of a system (component) is reflected by features which are main source of information for prognostics model to estimate RUL.
- However, there is no unique way to select most relevant features that are predictable and contribute for better RUL estimation and the predictability should be assessed according to prediction model as well as horizon of prediction.

INTRODUCTION

- In this paper a methodology for integrated knowledge-based management of industrial production plant is proposed.
- Suitable metrics for the main components of the cost/benefit analysis are under investigation:
 - component's and whole plant performance assessment,
 - efficiency of operational activities estimation and
 - maintenance expenses evaluation.
- A RUL based method for CBM is presented as a functionality of the integrated control system.

BIOMASS AND ITS ENERGY POTENTIAL

- Biomass refers to all forms of plant-derived material that can be used for energy:
 - wood,
 - herbaceous plants,
 - crop and forest residues,
 - animal wastes etc.
 - Biomass is generally regarded as a low-status fuel.
 - Wood and wood wastes (e.g. sawdust, timber slash and mill scrap) are the preferable kind of biomass for pellet production.
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BIOMASS AND ITS ENERGY POTENTIAL

- The Bulgarian Executive Forest Agency has estimated that the amount of wood in the forests of Bulgaria totals 643 million m³, and it is growing annually by 14.4 million m³.
 - The yield for 2012 was 5.6 million m³, so extraction of about 3 million m³ can be used in biomass plants.
 - The introduction of fast growing crops (such as willow) could supply big amount of sustainable energy and very low noxious emissions during combustion. It would also create numerous rural jobs in areas where most of population is living.
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BIOMASS AND ITS ENERGY POTENTIAL

- Agricultural waste is a potentially huge source of biomass for energy.
 - Every year, millions tonnes of straw are produced world-wide and are still being burned in the field or ploughed back into the soil, instead to be used its potential as an energy resource.
 - There is a growing recognition that the use of biomass in larger commercial systems improve natural resource management.
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STATEMENT OF THE PROBLEM

- CBM is a maintenance strategy aimed at extending machine life, increasing productivity, and lowering the daily operating costs.
 - Unlike periodic maintenance where services are based upon scheduled intervals, CBM relies upon actual machine health to dictate when and what maintenance is required and delivers better control.
 - It can be initiated according to the state of a degrading system that is monitored through various measures that typically describe the state of the system.
 - Once the degradation characteristic crosses a specified threshold, action to perform the maintenance is triggered.
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STATEMENT OF THE PROBLEM

- In maintenance field, prognostics considered as a key task within CBM that predicts RUL of machinery under certain operational modes and facilitates decision making.
 - Therefore, within CBM concept, the whole aspect prediction and failure can be viewed as set of certain activities that must be performed in order to accomplish predictive maintenance procedures .
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STATEMENT OF THE PROBLEM

- Prognostics can be categorized mainly into three approaches:
 - experience based,
 - model based and
 - data driven methods.
 - Among these approaches data driven methods are considered to be a trade-off between experience based and model based approaches.
 - They are increasingly applied to machine prognostics due to their effectiveness and ability to overcome limitations of latter categories.
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STATEMENT OF THE PROBLEM

- Intelligent systems that are used for condition-based fault diagnosis fall into three categories:
 - rule-based diagnostic systems,
 - model-based diagnostic systems and
 - case-based diagnostic systems.
 - Rule-based systems detect and identify equipment faults in accordance with the rules representing the relation of each possible fault with the corresponding condition.
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STATEMENT OF THE PROBLEM

- A model-based system uses various mathematical, neural network and logical methods and compares the real time monitored condition with the model of the object in order to predict the fault behavior.
 - Case-based systems use historical records of maintenance cases to provide an interpretation for the actual monitored conditions of the item.
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STATEMENT OF THE PROBLEM

- A record of all previous incidents and system malfunctions along with their maintenance solutions are stored in a computer.
 - If a fault similar to a stored case occurs, the case-based diagnostic system will pick up a suitable maintenance solution from the case library.
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BIOMASS PELLETT PRODUCTION

■ ***Pellet Processing***

- Some problems are associated with the use of biomass (sawdust, wood chips or agricultural residues) as fuel, mainly related to the high bulk volume, which results in high transportation costs and requires large storage capacities.
 - High moisture content can result in biological degradation as well as in blocking the in-plant transportation systems.
 - In addition, variations in moisture content make difficult an optimal plant operation and process control.
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BIOMASS PELLETS PRODUCTION

- Pelletizing is a method to increase the bulk density of the biomass by mechanical pressure.
 - Pellets are cylinders with diameter of 6-10 mm, with low moisture content (about 8% wet basis), and with a high bulk density (more than 600 kg/m³) for an efficient transport and storage.
 - The increased energy density and more homogeneous composition results in better combustion control and thereby higher energy efficiency.
-

BIOMASS PELLET PRODUCTION

- A number of properties are commonly known to affect the quality of pelleting.
 - They can be divided from raw material depending and mechanical properties.
 - The mechanical main factors that improve the pelleting process are optimized die measures and pelleting pressure.
 - From the raw material depending properties include:
 - moisture content of the material,
 - density of the material,
 - particle size of the material and
 - characteristics of the materials.
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BIOMASS PELLETT PRODUCTION

- There are strong differences related to the processing of different kinds of biomass raw materials.
 - Hardwood (such as beech or oak) sawdust requires higher pressure forces than softwood and conifers.
 - For wet raw material processing, the highest energy requirement corresponds to the drying stage.
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BIOMASS PELLET PRODUCTION

- **Pellet Production Plant**
 - A small factory for industrial biomass pellet production is presented.
 - The simplified scheme of the plant is presented in Fig. 1.
 - Pictures of inside and outside views are shown in Fig. 2.
 - The plant is divided in the following parts:
 - storage area for raw materials;
 - place for primary processing of raw materials;
 - drying unit;
 - milling and further processing units;
 - pellet presses,
 - cooling installation and packaging machines;
 - indoor storage place for the ready production.
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BIOMASS PELLET PRODUCTION FLOW CHART

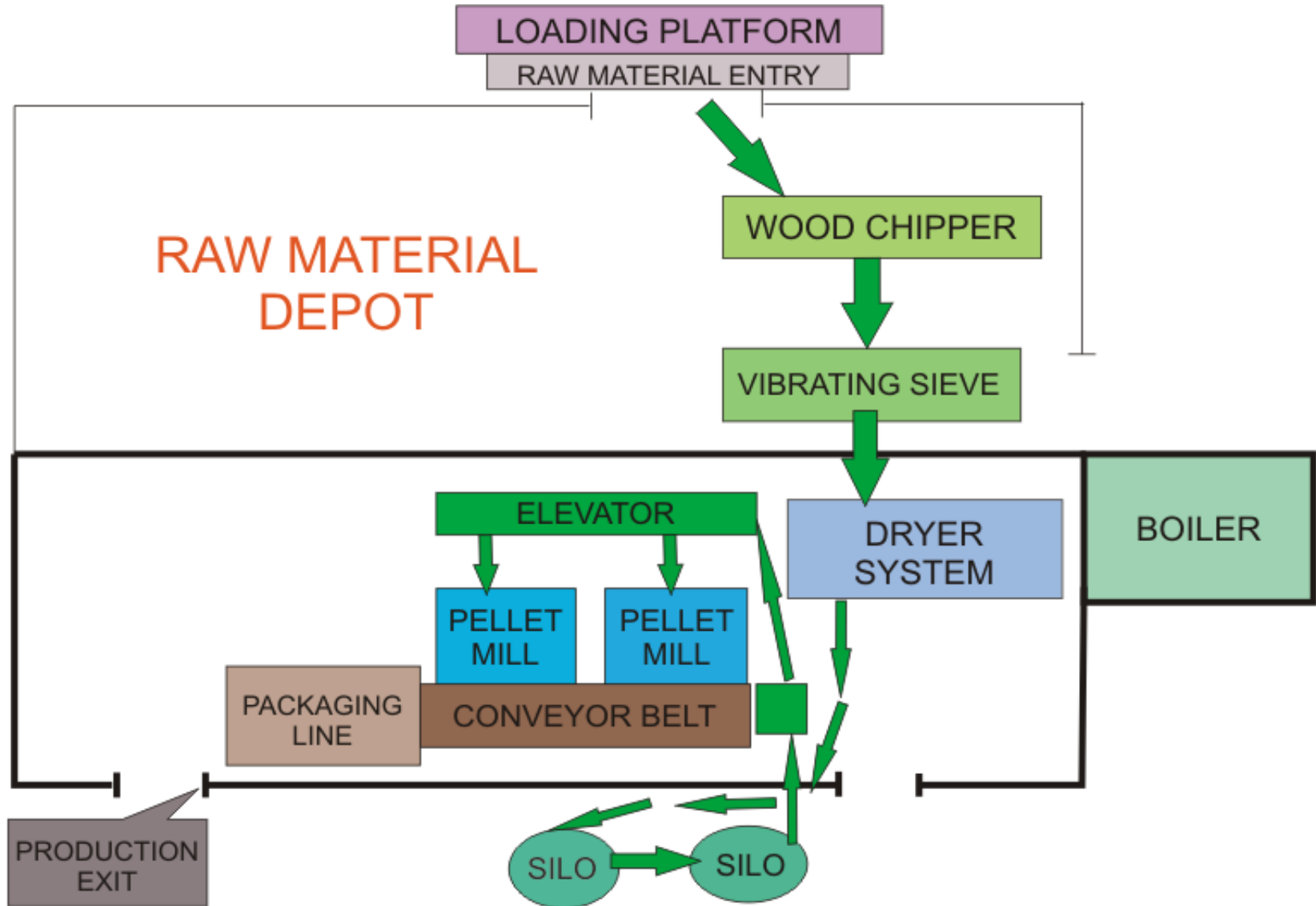


Fig. 1. Scheme of the pellet manufacturing plant



Fig. 2. Inside and outside views of the plant

BIOMASS PELLET PRODUCTION

- The plant has the following main characteristics:
 - capacity – $0.7\div 0.9$ *t/h*;
 - working hours per day – 18;
 - annual productivity – 4320 *t*;
 - consumption of electricity – 300 *kWh/t*;
 - heat consumption – 2500 *MJ/t*.
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BIOMASS PELLETT PRODUCTION

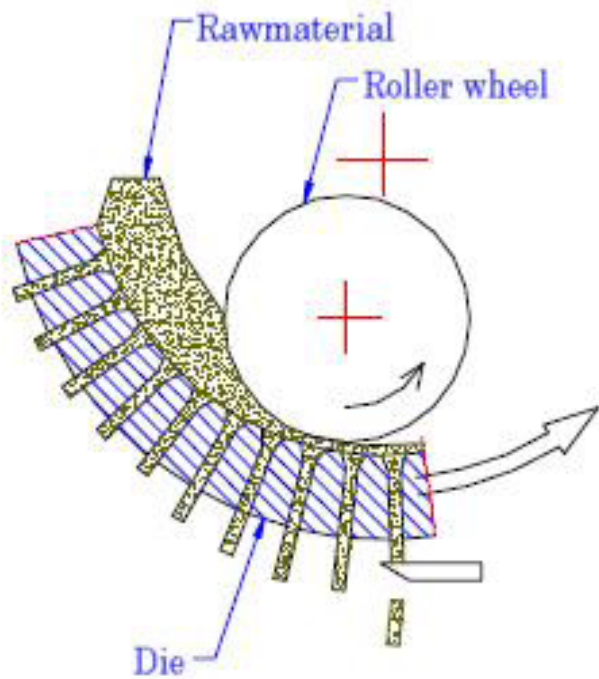
- Legacy control system contains two SCADA sub-systems for measurement the basic technological parameters – temperatures, flow rates, moisture.
 - The dryer is equipped with PID control system for moisture stabilization of the row material acting on its flow rate.
 - Conventional local controllers, relay systems and safety devices are installed.
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BIOMASS PELLETT PRODUCTION

- No supervisory functions for
 - *optimization,*
 - *coordination,*
 - *multivariable control,*
 - *maintenance or*
 - *bridging with business and management level*
are stipulated.
 - Plant operations are based on regime instruction and are hand-operated.
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BIOMASS PELLETT PRODUCTION

- A pellet press is composed of a die and two rollers.
 - The rotation of the die and roller pressure forces material through the die holes, compressing the material into pellets (Fig. 3).
 - The density of the pellets depends on
 - the length (L) and the diameter (D) of the apertures in the die,
 - the condition of the die and rollers,
 - the roller adjustment and
 - the raw material properties.
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Ring die
Roller wheel inside

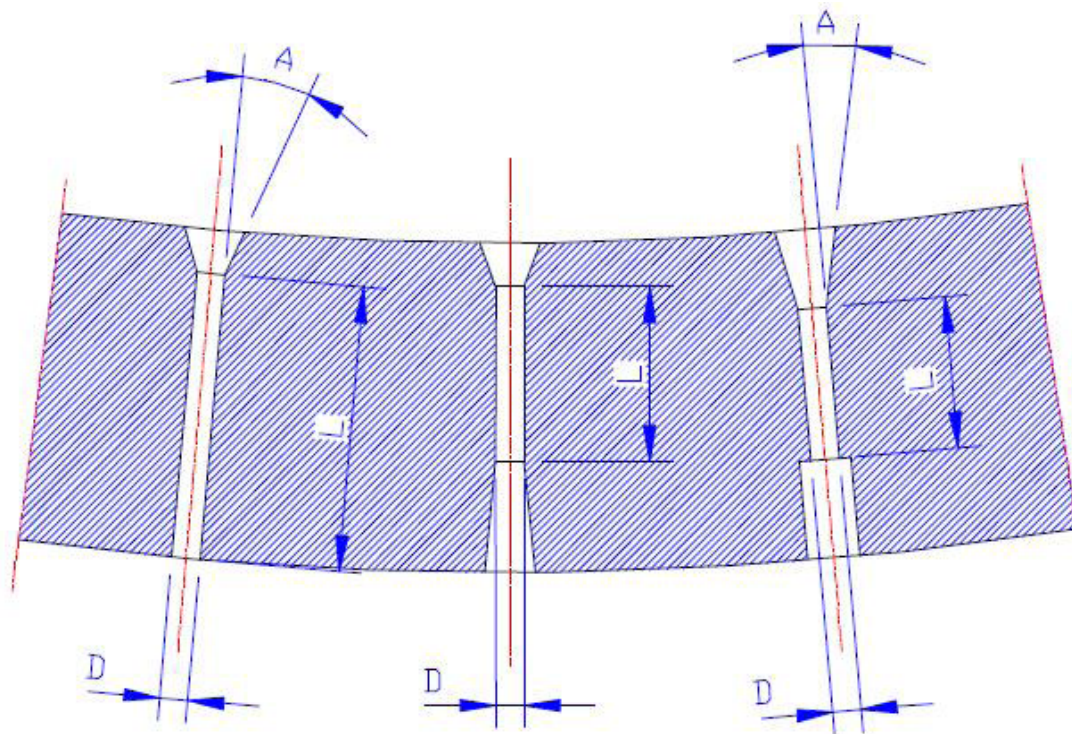


Fig. 3. Ring die and its measures

BIOMASS PELLETT PRODUCTION

- Dies need to be selected based on the kind of biomass.
 - A balance needs to be found between pellet durability and throughput.
 - The prolonged residence time in a die gives positive effects on the durability of the pellets.
 - Gap between roller and die is an important variable making good pellets.
 - Increasing gap-size (about 2–2.5 mm) the pellet hardness and durability are enhanced.
 - A further increase in gap-size (about 4–5 mm) causes negative effect.
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BIOMASS PELLETT PRODUCTION

- For the considered pellet production plant the mill machine data are the following:
 - die diameter – 480 *mm*;
 - rollers diameter – 184 *mm*; 189 *mm*; 194*mm*;
 - *L/D*-ratio – 17:6 ÷34:6;
 - pressing pressure – 80 ÷ 100 *MPa*;
 - temperature of the material ~80 °C.
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BIOMASS PELLETT PRODUCTION

- Characteristics of the produced pellets:
 - diameter – 6 *mm*;
 - length – 10 ÷ 30 *mm*;
 - moisture content – 8 ÷ 12%;
 - calorific value – 4200 ÷ 5000 *kcal/kg*;
 - density – 1.25 ± 0.06 *kg/dm³*;
 - hardness (mechanical strength) – 92.5%.
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BIOMASS PELLETT PRODUCTION

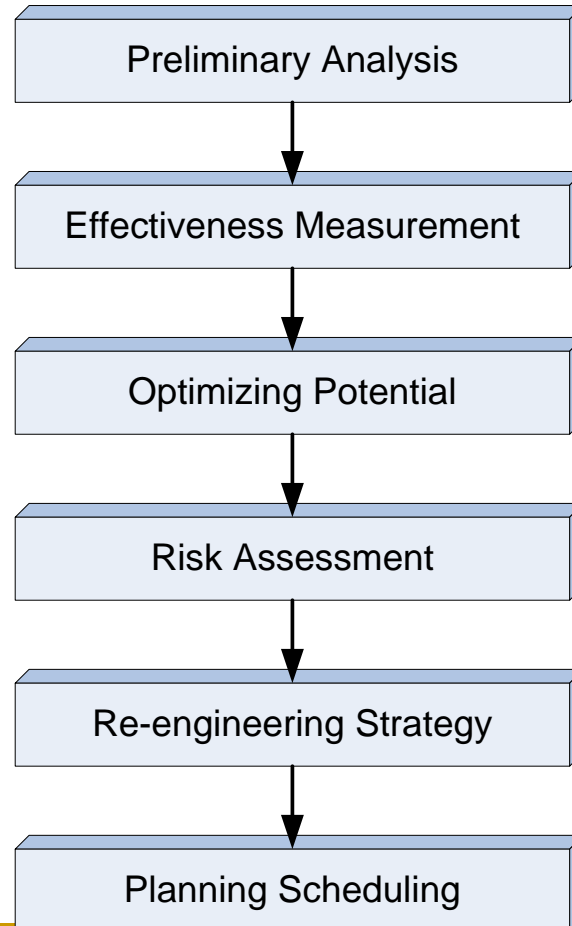
- The production costs per 1 tonne pellets include:
 - for raw material ($6 m^3$) – 60 €;
 - 150 kg chips for the boiler – 11 €;
 - transport fuel for feeding both the boiler and the dryer system – 10 €;
 - energy consumption – 25 €;
 - maintenance (cost of parts, repairs, etc.) – 15€;
 - personnel cost – 15 €.

PROBLEM STATEMENT

- **In this work the next targets are followed:**
 - To define the Re-Engineering (Re-E) strategy for small size pellet production plant (PPP)
 - To apply accepted strategy for incremental Re-Design (Re-D) to the most promising subsystems of the pellet production plant
 - To implement Fuzzy Logic (FL) in successive Re-design of PPP
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RE-ENGINEERING PROCEDURE

- The procedure of re-engineering adopted in this work is shown in Fig. 4



RE-ENGINEERING PROCEDURE

■ **Preliminary Analysis**

- It aims to clarify the main features and limitations in the framework of which the Re-E will be realized:

- *Efficiency* – the ability to determine

- hourly productivity (throughput), P t/h,
 - costs for energy consumption (heat and electricity) kWh/t),
 - production costs (for raw material, personnel, etc.), €/t),
 - maintenance costs €/t.
-

RE-ENGINEERING PROCEDURE

■ **Preliminary Analysis**

- *Functional requirements* – clarifying
 - the lack of necessary measurements,
 - process control,
 - optimization (static and dynamic),
 - interfaces with the upper levels of hierarchy,
 - a system for preventive and predictive maintenance,
 - system for safety and availability.
-

RE-ENGINEERING PROCEDURE

- **Preliminary Analysis**

- *Obsolescence* –

- architecture;

- software compatibility in current commercial free or COTS platforms;

- interfaces,

- communication.

- *Environmental compliance* – to bring in conformity with the national and EU- legislation.

RE-ENGINEERING PROCEDURE

- ***Determination of the Efficiency***
 - *Process efficiency:*
 - measurements (direct, indirect),
 - indexes,
 - quality indicators,
 - risk.
-

RE-ENGINEERING PROCEDURE

- ***Determination of the Efficiency***
 - *Performance management systems:*
 - availability,
 - range of adjustable parameters,
 - performance (accuracy, multimodality,
 - speed, fault tolerance),
 - technical and algorithmic advances.
 - *System efficiency –*
 - coordination,
 - communication,
 - security.
-

RE-ENGINEERING PROCEDURE

■ *Optimizing Potential*

- The presence of optimizing potential is critical for Re-E planning.
- The optimizing potential is calculated as the distance between the existing system and the reference system:

$$Q = \|J_e - J\| \quad (1)$$

- where J , J_e are the indexes of the current and reference systems.
-

RE-ENGINEERING PROCEDURE

■ ***Optimizing Potential***

- Two types of optimizing potential are considered in this study:
 - Optimizing potential of the technological system with the following attributes:
 - hourly productivity P t/h;
 - quality – H ;
 - production costs EP €/t;
 - energy costs EW kWh/t;
 - personnel costs ES €/t;
 - maintenance costs EM €/t:

$$JT = \langle P, H, EP, EW, ES, EM \rangle \quad (2)$$

- The quality indicator H is defined with usage of a scale in the range $[0,10]$.
-

RE-ENGINEERING PROCEDURE

■ ***Optimizing Potential***

- Optimizing potential of the control system with the following attributes:

- accuracy (e.g. mean square error) – σ ,
- robustness (e.g. μ) – ζ ;
- multimodality – ψ ,
- fault tolerance – π ,
- complexity – δ :

$$JC = \langle \sigma, \zeta, \psi, \pi, \delta \rangle \quad (3)$$

- The attributes ψ, π, δ are defined as nondimensional variables on a scale in the range $[0,10]$.
- The efficiency indexes JT and JC can be applied at different levels.

Table 1.

	technological system	control system	optimization subject
1	single element	basic regulator	parameters
2	unit (aggregate)	multiconnected control	subsystem
3	production	supervisory control	system

RE-ENGINEERING PROCEDURE

■ **Risk Assessment**

- ❑ Learned lesson of Re-E and Re-D show that there is significant investment risk.
- ❑ It is different at the various steps of the incremental Re-E and therefore its evaluation is essential in the decision making process.
- ❑ An additive form of risk assessment for Re-E is accepted:

$$R = \sum_{i=1}^5 \beta_i R_i \quad \sum_{i=1}^5 \beta_i = 1 \quad (7)$$

- ❑ where R_i are the partial risks, β_i are the weighted coefficients.
 - ❑ The partial risks can be scalars, but they could also have their own components depending on attributes.
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RE-ENGINEERING PROCEDURE

■ **Risk Assessment**

- R_1 is the risk of incorrect assessment of the actual optimization potential
 - R_2 is the risk of unexpected expenses that may be:
 - For additional operator training
 - To eliminate defects not considered in the contract for Re-D
 - To include the omitted in the contract, but necessary functionality without which the Re-E is not profitable.
 - R_3 is the risk that the period for the return of investments (ROI) will exceed the expected one (e.g. 6 years).
-

RE-ENGINEERING PROCEDURE

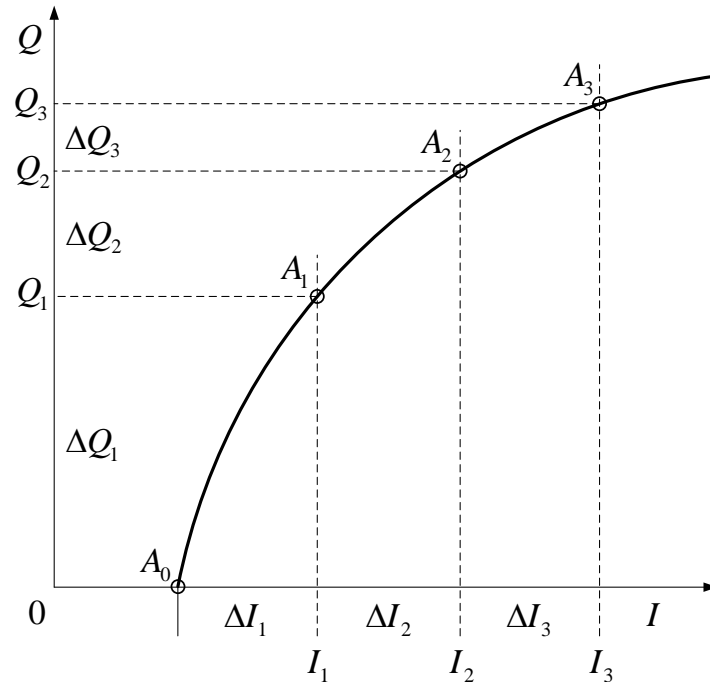
■ ***Risk Assessment***

- ❑ R_4 is a risk of failure of guarantees given by the developer company. Often the Re-E is implemented by small engineering firms who don't have the capabilities of the big companies in the field.
 - ❑ R_5 is an additional risk from the operation re-engineered device/unit, e.g. sensor failures, hacker attacks, communication drawbacks.
 - ❑ Therefore, the realistic risk assessment especially for the SME is significant, because of the limited resources and the market volatility.
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RE-ENGINEERING PROCEDURE

■ *Re-Engineering Strategy*

- Simplified cost/benefit curve is presented in Fig. 5.



- Incremental Re-Engineering and Re-Design is discontinuous.
- A number of successive steps should be carried out in order to realize estimated optimizing potential.

RE-ENGINEERING PROCEDURE

- ***Re-Engineering Planning and Scheduling***
 - In SME where the investment resources are limited the strategy realization could be connected with the cost orientated problem consideration.
 - In the same incremental stage of Re-E different sub-steps are possible.
 - More detailed analysis could show that a number of small low cost sub-steps is more beneficial than one single step.
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RE-ENGINEERING PROCEDURE

- ***Re-Engineering Planning and Scheduling***
 - The pellet manufacturing process strongly depends on the parameters of the raw material.
 - Thus the accepted Re-E is appropriate to be planned and scheduled on the basis of composition-property diagrams of different combinations of sawdust (*W*), straw (*S*) and agricultural waste (*A*).
-

RE-ENGINEERING PROCEDURE

- ***Re-Engineering Planning and Scheduling***
 - The main indexes of the pellets quality are hardness (h), durability (d) and calorific value (q), which determine the pellets price.
 - Composition-properties diagrams can be parameterized in terms of the indices h , d , q and the process variable φ .
 - This is an important step in the planning and scheduling of the pellets production process.
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RE-ENGINEERING OF PELLET PRODUCTION PLANT

■ ***Re-Engineering Sequence***

- Pellet production contains four main stages:
 - supply chain and preliminary processing;
 - drying;
 - extrusion;
 - cooling and screening.

 - In the existing legacy systems these processes are automated partially only with local feedback control systems.
-

■ ***Re-Engineering Sequence***

- Following the presented approach it was found that the appropriate Re-E strategy of the considered Pellet Production Plant (PPP) includes the following steps:
 - (1) Pellet Mill;
 - (2) Drying system;
 - (3) Supply chain.
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RE-ENGINEERING OF PELLET PRODUCTION PLANT

- ***Optimizing Potential of Pellet Mill Re-Engineering***
 - The pellet machine is of crucial importance for the pellets production.
 - The main tasks defined for Re-E consist of the following steps:
 - 1. Selection of a matrix in dependence on the type of the biomass.
 - 2. Optimal adjustment of the distance between the rollers and the matrix. The adjustment of the pressing rollers of the already selected matrix is an optimization problem.
 - 3. Condition Based Maintenance (CBM)
-

RE-ENGINEERING OF PELLET PRODUCTION PLANT

- A number of properties are commonly known to affect the quality of pelleting.
 - They can be divided from raw material depending and mechanical properties.
 - The mechanical main factors that improve the pelleting process are optimized die measures and pelleting pressure.
 - From the raw material depending properties include:
 - moisture content of the material,
 - density of the material,
 - particle size of the material and
 - characteristics of the materials.
-

- As some of the variables are not measured (material hardness) or they have non-quantitative nature (pellets quality), the fuzzy logic (FL) based approach for problem solving is accepted.
- In this task for the fuzzy logic inference (Fig. 7) a fuzzy rule base of the following type is created:

R_i : IF δ is δ_i and g is g_i and φ is φ_i : Then $k = k_i$

where δ is the distance between the rollers and the matrix (measured), g is a measure of the material hardness [$0 \leq g \leq 10$]; φ is the moisture content of the material at dryer outlet (measured), k is a measure of the pellets quality in a scale [$0 \leq k \leq 10$] (assessed by the operator).

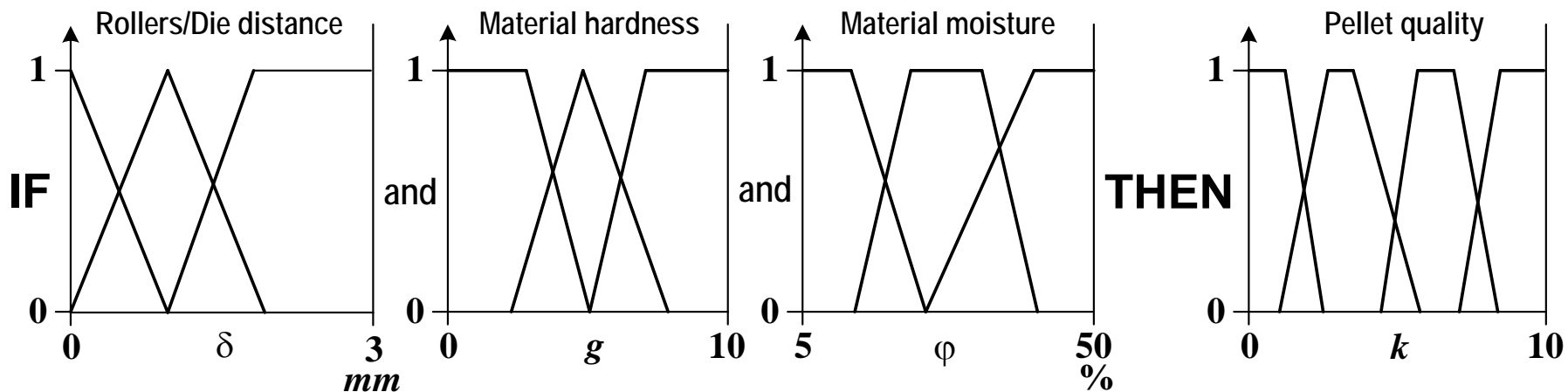


Fig. 7. Fuzzy Logic Inference procedure

- Besides the task of determining the expected pellets quality (Fig. 8a), the task of selecting an optimal gap δ at given other variables can be solved using FL (Fig. 8b).
- Similarly the problem of finding an optimal moisture content of the dried material φ is solved (Fig. 8c).

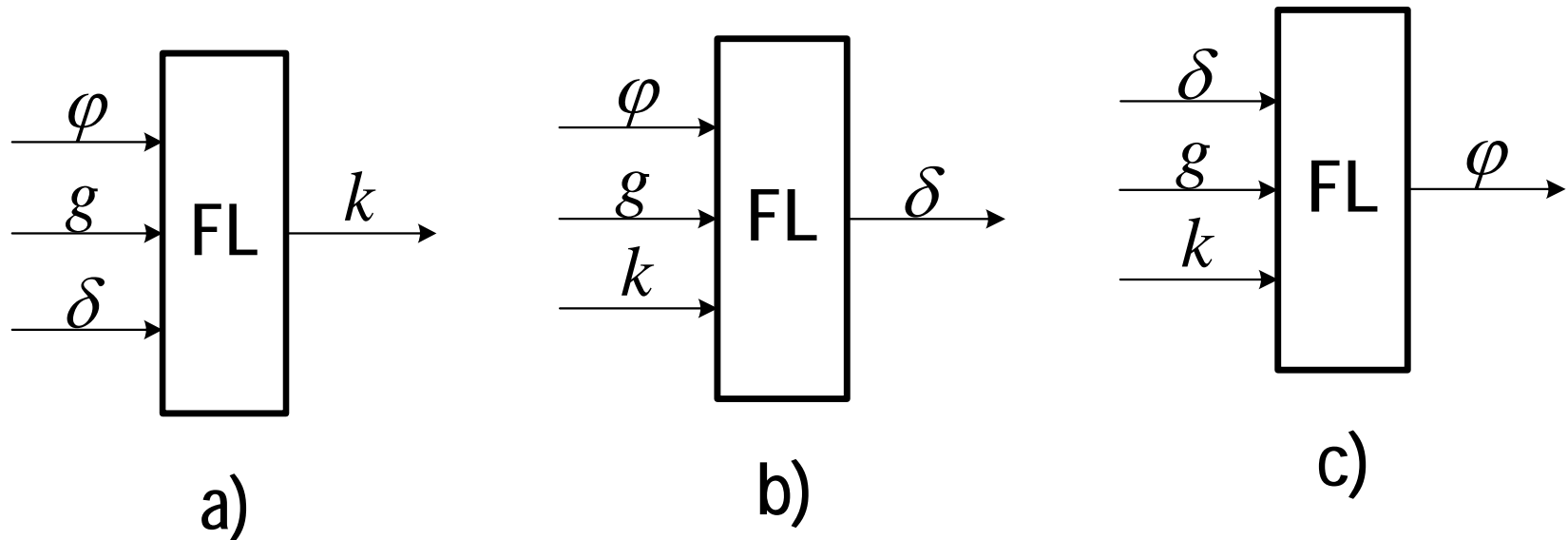


Fig. 8. Fuzzy Logic based models

INTEGRATION OF MANUFACTURING AND CONDITION BASED MAINTENANCE

- The CBM of the rollers and die using indirect degradation assessment is accepted.
 - It contains the following main functions:
 - Determination of the start of the inspection frequency of the rollers degradation;
 - Forecasting the RUL of the rollers;
 - Prolonging the RUL of the rollers by load reduction.
-

■ Condition Based Maintenance (CBM)

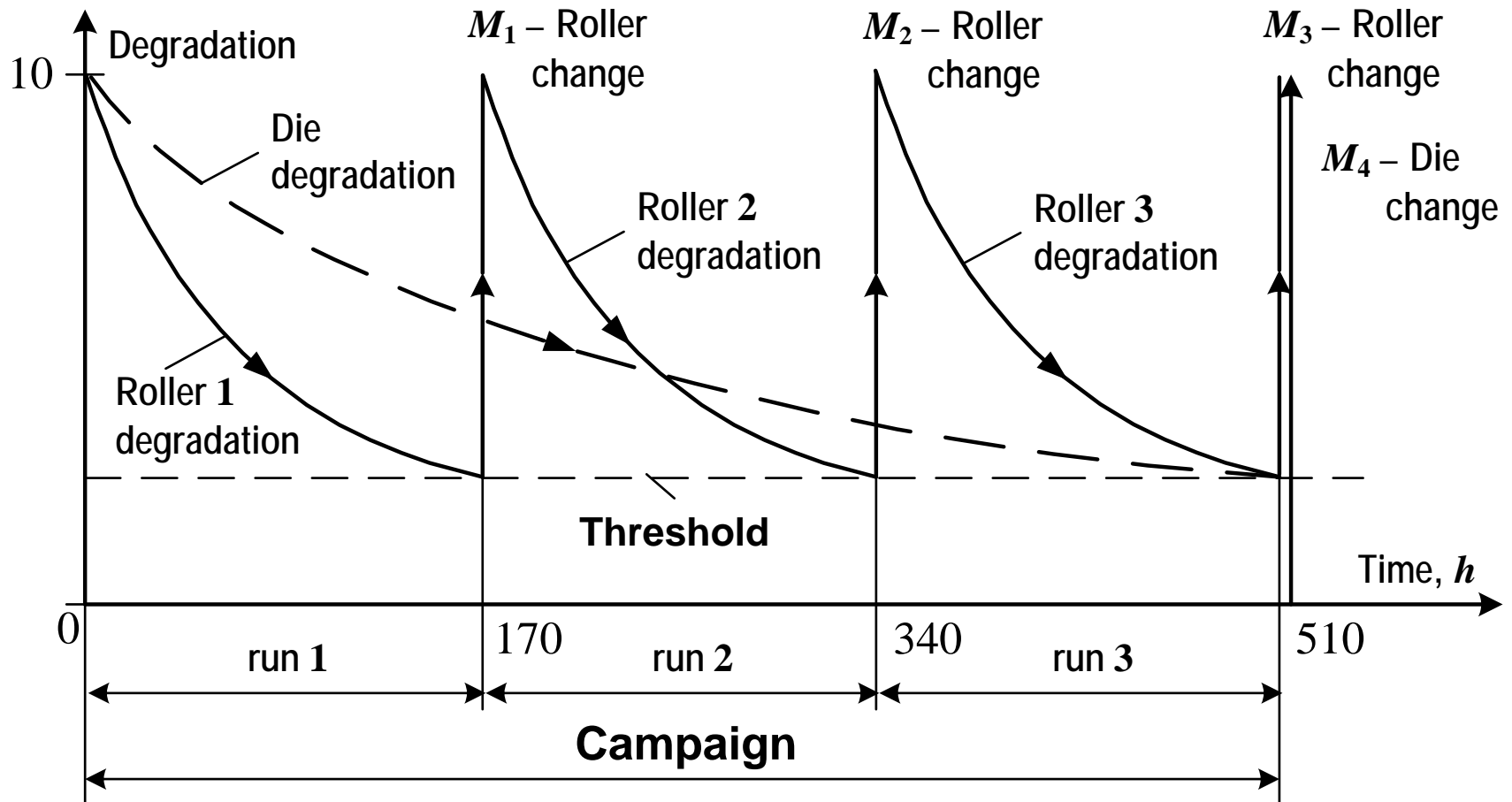


Fig. 9. Maintenance scheduling of pellet mill

- In Fig. 10 the main maintenance actions are given:
 - M_1 – inspection beginning, M_2 – load change ($L_1 < L_0$), if it's appropriate, $M_2 \rightarrow M_3'$ rollers changing at reduced load L_1 and threshold T_1 and T_2 at initial load L_0 , $M_4 \rightarrow M_4'$ rollers changing at reduced load L_1 and threshold T_1 and T_2 .

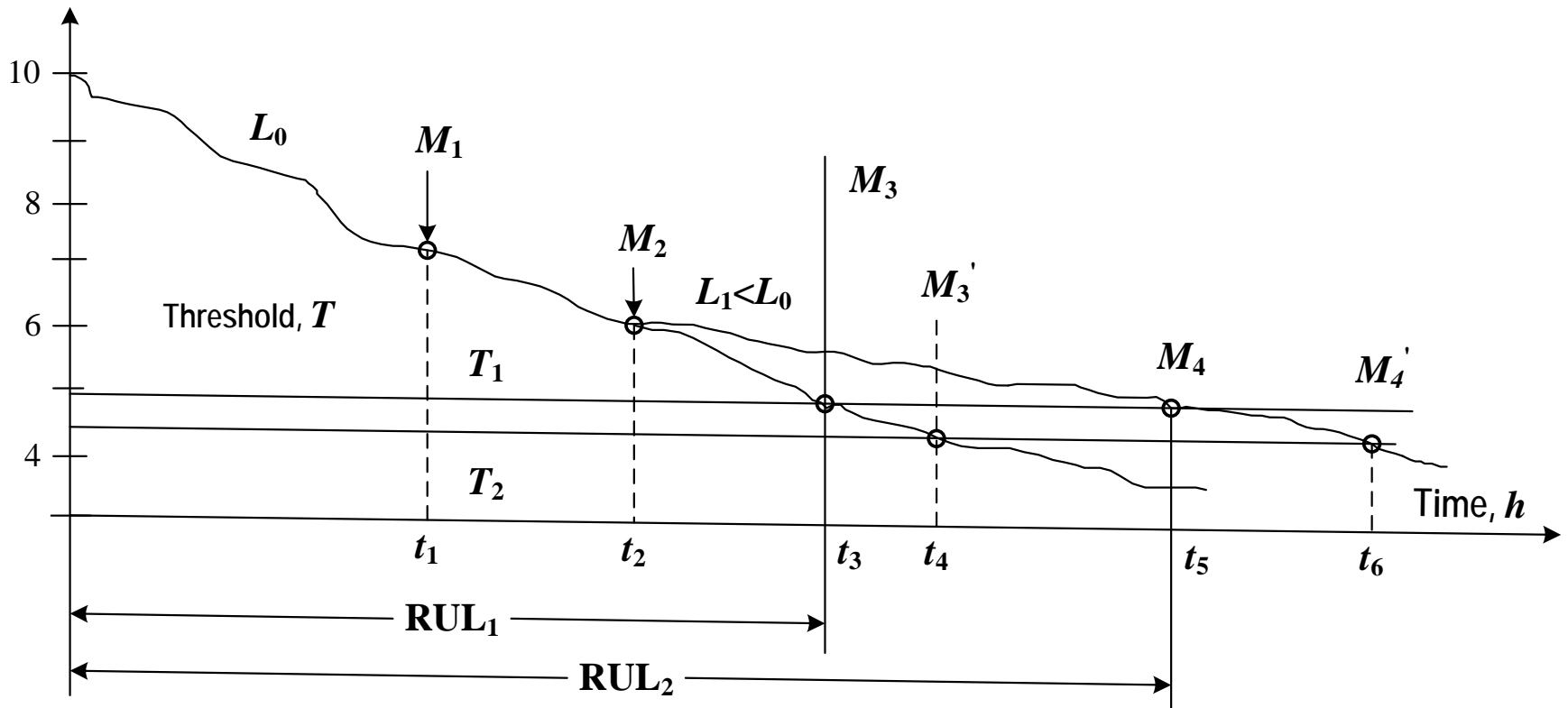


Fig. 10. CBM strategy

- During the operating an adaptive threshold T can be used, depending on the market conditions (demand and price).
- If it is profitably at a given market situation the load reducing could also be done.
- Thus, the quality and productivity of pellet mill are closely related to the RUL and the threshold T .

- The RUL predicting can be performed on the base of fuzzy logic.

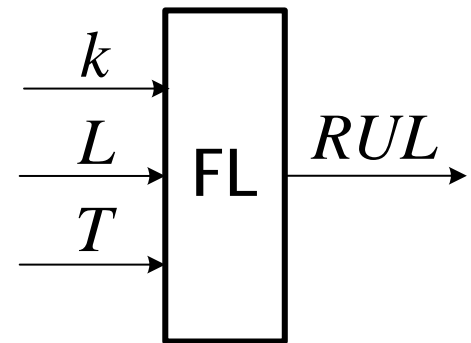


Fig. 11. RUL Fuzzy model

CONCLUSIONS

- In this paper, integration of condition based maintenance and manufacturing as unified problem is investigated.
- Method for degradation level estimation and prediction of the most loaded elements in extruding part is performed and analyzed.
- Development of maintenance model and its integration in the management system of pellet production plant is considered.
- The usefulness of the CBM of pellet mill is discussed with implementation of fuzzy logic based procedures for current state inference of the rollers and RUL prediction of the pair die/rollers.

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MANAGEMENT AND
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**NIKOLINKA
GEORGIEVA
HRISTOVA**

Thank You

